

The Center for Star Formation Studies

D. Hollenbach, K. R. Bell, G. Laughlin

The Center for Star Formation Studies, a consortium of scientists from the Space Science Division at Ames and the Astronomy Departments of the University of California at Berkeley and Santa Cruz, conducts a coordinated program of theoretical research on star and planet formation. Under the directorship of D. Hollenbach (Ames), the Center supports postdoctoral fellows, senior visitors, and students; meets regularly at Ames to exchange ideas and to present informal seminars on current research; hosts visits of outside scientists; and conducts a week-long workshop on selected aspects of star and planet formation each summer.

In June 2000, the Center worked together with researchers from the Arcetri Observatory (Florence, Italy) to hold an international workshop entitled "High Mass Star Formation: An Origin in Clusters." The week-long workshop, held in Volterra, Italy, had approximately 175 attendees, and included an invited talk by D. Hollenbach on "Star Formation and the Fluctuating Ultraviolet Field in the Galaxy."

One focus of the NASA Ames portion of the research work in the Center in FY00 involved the effect of ultraviolet radiation from young massive stars on the interstellar medium of a galaxy. The interstellar medium of a galaxy is the gas and dust that lie between the stars. Most of the gas is hydrogen; the dust mass is only about 1% of the gas mass. The gas and dust reside in various components, often characterized by the gas density in the component. The densest and coldest component is the molecular clouds; this component forms stars. Diffuse clouds are less dense than molecular clouds; they are primarily cold atomic hydrogen. The warm medium consists of neutral and ionized gas at very low density and relatively

high temperature. The star formation rate in a galaxy depends on the rate at which molecular clouds can be formed, because only this component forms stars. The molecular clouds are thought to form by the coalescence of diffuse clouds into opaque, self-gravitating clouds. However, high rates of star formation lead to high populations of massive stars that radiate copious ultraviolet flux. The ultraviolet flux in turn heats up the diffuse clouds in the interstellar medium and transforms them into a warm medium. Because a warm medium is unlikely to form molecular clouds, the lack of diffuse clouds cuts off the supply of molecular clouds in a galaxy, thereby cutting off the star formation rate. This scenario then provides a self-regulation mechanism that controls the rate of star formation in a galaxy.

Another focus of the Ames portion of the Center research in FY00 involved a collaborative theoretical study of the conditions that determine whether a collapsing molecular cloud core of gas and dust gives rise to a single star surrounded by planets or to a binary star system. This work focused on the realization that the molecular cloud cores that precede star formation can have equilibrium configurations that are nonaxisymmetric (lopsided). An analytical study carried out by the Center reported on the discovery and the properties of a sequence of these unusual egg-shaped equilibrium configurations. The analysis shows that these configurations can collapse in a way that may naturally produce either binary or single stars, depending on the initial degree of distortion.

The theoretical models of the Center have been used to interpret observational data from such NASA facilities as the Infrared Telescope Facility (IRTF), the Infrared Astronomical Observatory (IRAS), the Hubble Space

Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements for future missions such as the Stratospheric Observatory for

Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF).

Point of Contact: D. Hollenbach
(650) 604-4164
hollenbach@ism.arc.nasa.gov

The Formation and Dynamics of Planetary Systems

Gregory Laughlin

Progress was made in FY00 in numerous areas bearing on the overall problem of the formation and evolution of planetary systems. Specific topics of research have ranged from the earliest stages of star formation through the long-term fate of the Earth, and they are described in four peer-reviewed research papers.

In the present-day solar system, the sun contains 99.9% of the mass, whereas the planets contain the bulk of the system angular momentum. The clouds of gas and dust that collapse to form star-planet systems, however, are essentially in uniform rotation. One of the major unsolved puzzles in the theory of star and planet formation thus involves the detailed mechanism by which mass is transported inward onto the protostar while angular momentum is simultaneously pushed outward. It is believed that spiral gravitational instabilities play a key role in eliciting angular momentum transport, but a full description of how spirals grow and operate on a global scale (that is, throughout the entire protoplanetary disk) is not understood. Considerable theoretical progress was made in this area by performing a stability analysis of idealized singular isothermal disks. This research, carried out and published in collaboration with researchers at the University of California at Berkeley, Arcetri (Italy), and UNAM (Mexico), has clearly explained the role of the corotation

amplifier in allowing spiral waves to grow. This in turn gives us a clearer theoretical picture of the very earliest stages of star and planet formation.

A second line of inquiry has developed a way to constrain the conditions under which our own solar system formed. The outer giant planets in our solar system all have nearly coplanar, circular orbits. This orderly configuration indicates that the sun and the planets have always existed in relative isolation. If another stellar system had passed within several hundred astronomical units of the sun, gravitational perturbations would have scattered the outer planets (particularly Neptune) into highly eccentric, inclined orbits. An extensive set of Monte Carlo star-planet scattering calculations has shown that the solar system likely formed in an aggregate containing fewer than 1500 stars, and thus was not born in a dense stellar cluster (resembling, say, the Trapezium region in Orion). Primitive meteorites, however, contain daughter products of extinct radioactive elements that have half-lives of one million years or less. In order to explain the presence of such short-lived isotopes in meteorites, it has been proposed that either (1) the presolar nebula was enriched by a nearby supernova explosion, or alternately that (2) x-ray flares associated with the nascent sun were able to create radioactive atoms via